ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPTS103

FIRST RESULTS OF THE ANALYTICAL METHOD USED TO REDUCE DOWNTIME RISK AT AN ACCELERATOR FACILITY*

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Abstract

The Los Alamos Neutron Science Center (LANSCE), like many other accelerator facilities, was built decades ago and has been repurposed when new missions were adopted. With an ongoing beam availability expectation of at least 80% delivered to the Experimental Areas (EAs), a balance between cost of spare equipment and budget has always been a challenge. Beam availability data has been meticulously captured and binned over the years to completely characterize the Structures, Systems and Components (SSCs) and other factors that have caused or contributed to accelerator downtime. Over these years, a critical spares list prioritized the spare equipment purchases that were deemed most important by the management team. In the span of the years 2013 – 2015, significant accelerator upgrades and equipment replacements were performed in a set of activities known as LANSCE-RM. Last year, a new risk-based approach was developed by the management team that included an analytical assessment and a quantitative evaluation of probability and consequence. The resulting risk register (risk-based equipment list) is being used to guide decisions on funding requests and provide justification to mitigate operational risks. A paper by the same authors was published at LINAC 2018 describing this risk-based approach that serves to reformulate the critical spares list. This paper, in the sections that follow, expands on the approach by detailing the steps taken that led to the first risk register. Additionally, it evaluates the historical unscheduled beam downtime at LANSCE compared to the current funding allocation choices made to increase the availability.

Introduction

Previous work was completed to establish a systematic approach to improving beam availability at an accelerator facility [1]. The present work expands on the previous methods, the prioritized equipment list and risk analyses through further examination of results. This paper divulges the first risk register and describes year-by-year trends in availability data.

When thousands of SSCs are vital to the operation of the LANSCE accelerator, organizing, binning and reporting a meaningful downtime record is absolutely vital to improving availability. The operations group at LANSCE has continuously collected and binned the data over the years to capture the SSCs responsible for downtime [2, 3]. These data are recorded by the Accelerator Operations Manager on algorithm enhanced spreadsheets. The downtime statistics are processed and reported weekly to equipment owners to take action on the data, if necessary. Downtime reports are generated to capture and explain the longer duration events. The facility is held accountable to meeting the uptime metric negotiated annually with its sponsors.

At LANSCE, availability data is tracked for each of the five EAs. For the sake of simplicity, Target 1's (Lujan Center) availability will be described here. In fact, Target 1 is the strictest indication of the overall health of the entire machine since it resides downstream of several integral beamline delivery sections (Figure 1, Lujan target = Target 1):

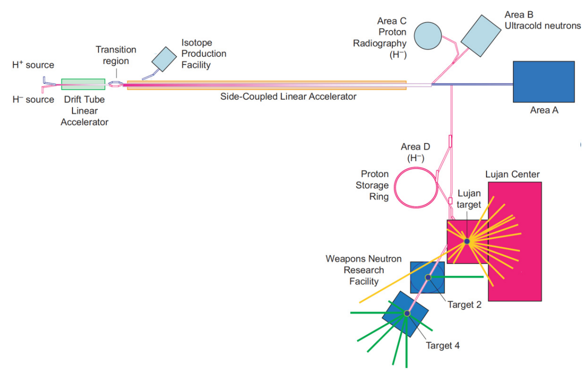

Figure 1: Pictorial Representation of LANSCE.

LANSCE Availability Data

Mining the data collected since 2010, Figure 2 shows the availability at Target 1 over the past 9 run cycles. Note that these run cycles varied in length between five and seven months with the shorter durations occurring during the LANSCE-RM set of activities (2013-2015).

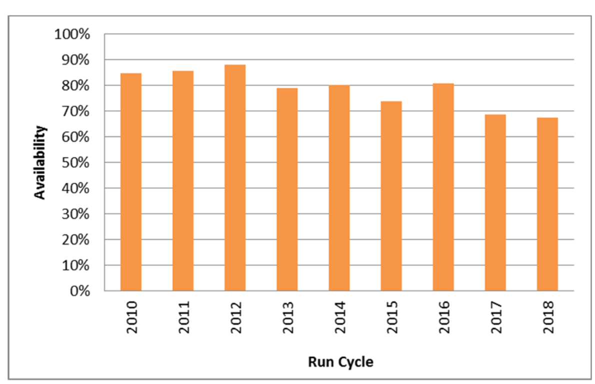

Figure 2: Availability of Lujan Center EA (Target 1).

* Work supported by the United States Department of Energy, National Nuclear Security Agency, under contract DE-AC52-06NA25396
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As seen in Figure 2, the availability for Target 1 has been trending down since a peak in 2012. The explanation for this trend involves several unrelated failures that caused the majority of the downtime:

1. Module 4 RF window arcing in the Drift Tube LINAC, (DTL, 2013).
2. Diagnosis and repair of an overheating quadrupole magnet in the Coupled-Cavity LINAC (CCL, 2014).
3. H- ion source failures and DTL structure arcing (2015).
4. Module 3 RF window arcing in the DTL, repaired by depositing a metallic thin-film coating on the window (2016).
5. Beam tune-up and vacuum problems due to incorrect beam transport settings in the Coupled-Cavity LINAC (2017).
6. Failure of a septum magnet in the proton storage ring (2018).

All of the above failures have been resolved. Downtime data for LANSCE is binned by SSC (Figure 3). Trends or reoccurring failures apparent in the data are elevated in attention so that appropriate responses can be formulated. Unusual or longer downtimes are acted upon by performing brainstorming by Subject Matter Experts (SMEs), root cause analyses and developing corrective actions. The threshold for performing analyses and corrective actions is a failure causing greater than 8 hours of unscheduled downtime. During the run cycle, repairs are made as soon as possible by the appropriate skill sets:

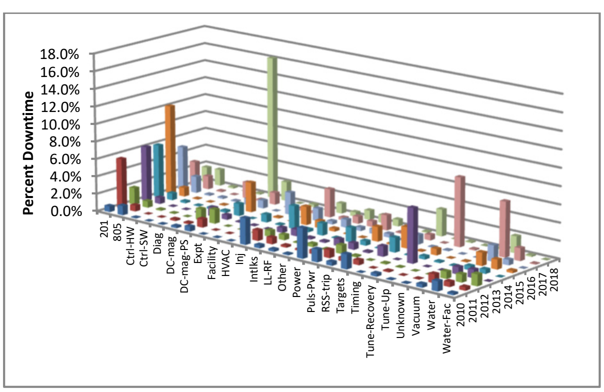

Figure 3: Annual Downtime Data for Target 1, Binned by SSC: DTL = 201, CCL = 805.

Referring back to the list of six failures above, those items are captured in the 3D plot of Figure 3; downtime in the Drift Tube LINAC (201) is greater than or equal to 5% in the years 2011, 2013, 2014, 2015 and 2016; Vacuum Systems is greater than 5% in 2017 and DC Magnets is greater than 15% in 2018. Although the 7% downtime in 2013 is binned in the category Tune-Recovery, that problem was essentially an overheating magnet caused by poor electrical connections which was not apparent at first. Although the occurrences summarized were not the only failures, they were the most significant and difficult ones to recover. There is an ongoing concerted effort at LANSCE between all equipment owners in the diagnoses, repair and recovery from unscheduled downtime.

As hinted in the six downtimes listed, the specifics of the failures and their associated corrective actions were implemented to solve the problems permanently such that these SSCs will not score high in the equipment assessment. Because of this permanence, the downtimes can be described as acute problems. Alternatively, if an issue is reoccurring, trending in a negative direction, is an indication of poor equipment condition or needs a longer term solution, then a higher equipment assessment score is predicted. These types of SSCs can be described as chronic problems. With a higher equipment assessment score, SSCs displaying chronic behavior or condition are likely to have a higher score compared to other SSCs.

Risk Matrix and Risk Register

As explained in reference [1], the management team at LANSCE formulated and implemented a risk-based approach to improving accelerator availability. Beginning with an equipment assessment, each SSCs was rated according to several criteria to achieve an overall score in which to differentiate them. Categories such as serviceable spare inventory, obsolescence, effect on security and equipment condition were among the criteria rated by system owners. The higher the equipment assessment score, the more attention was to be focused on their contribution to unscheduled downtime.

Equipment ownership is divided among particular groups at LANSCE:

- AE – Accelerators and Electrodynamics
- IC – Instrumentation and Controls
- OPS – Accelerator Operations
- RFE – Radio Frequency Engineering
- MDE – Mechanical Design and Engineering

The system owners in these groups performed the equipment assessments that were later compiled into one list. The top 50 SSCs that ranked highest in the compiled equipment assessment became the risk matrix. Each of these 50 SSCs in the risk matrix were then scored for risk.

Probability and consequence of failure were defined using standard risk guidance (Table 1):

Table 1: Risk Analysis of SSCs

Probability Rating *(Select)*	Prob Value	Consequences Rating *(Select)*	Impact Value	Risk Exposure (Actual)	Risk Exposure

For simplicity, the probability and consequence were ranked 1, 2 or 3 with 1 as the lowest and 3 the highest. This technique resulted in "Risk Exposure" scores that were simply [Probability Value X Impact Value]. Again, the equipment owners performed the risk assessments and, once completed, the resulting risk matrix was sorted from highest to lowest risk score. Finally, risk mitigation solutions were constructed primarily through budgetary estimates of design, fabrication and/or procurement of the quantities of equipment that reduced the risk (Table 2).

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Table 2: Risk Mitigation Estimates

Method	Risk Response Description	Cost for Material and Labor for Design and Prototyping the Risk Response / $k	Duration for Design and Prototyping for the Risk Response (months)	Cost for Material and Labor for Procurement and Implmentation Risk Response / $k	Duration for Implementation of Risk Response (months)

A definite demarcation occurred in the risk matrix which consisted of a Top 12 of items that represented the highest risks. This list of highest risk SSCs became what is known as the risk register (Table 3). It should be noted that this first risk register tended to be SSCs of the chronic rather than the acute variety. This fact is because of the immediate solutions implemented by equipment owners when SSCs of the acute variety fail during the run cycle. Acute failures do not necessarily exhibit degrading performance or other fault predictable behaviors.

Table 3: Risk Register, Top 12 Risks

Risk ID	Risk Sub Area	Risk Description	Risk Type	Risk Category
IC-001	Diagnostics	Emittance measurements	Threat	Budget
IC-002	Software	MicroVAXes	Threat	Budget
IC-004	Hardware	RICE	Threat	Technical
IC-006	Software	VAX Computers	Threat	Budget
OPS-005	Shutters	Switches	Threat	Schedule
OPS-007	TMRS	TMRS Cask	Threat	Budget
IC-005	Hardware	Wire Scanner	Threat	Technical
IC-008	Hardware	BPPM	Threat	Technical
MDE-002	15QD01&02 → 48QD01&02	Quad Doublets, Modules 15-48, 66 magnets nearing end of life	Threat	Technical
MDE-005	01TBPS	Tank 1 Boost Pump System and Water distribution components near end of life	Threat	Schedule
MDE-006	03TBPS	Tank 3 Boost Pump System and Water distribution components near end of life	Threat	Schedule
MDE-007	04TBPS	Tank 4 Boost Pump System and Water distribution components near end of life	Threat	Schedule

The first risk register for LANSCE in Table 3 shows the Top 12, highest risk SSCs as the result of the equipment assessments and risk analyses processes. As of this writing, all 12 of these SSCs have funding allocated that either partially or fully reduces their probability and/or consequence ratings. As the mitigations for these 12 are implemented, they will drop off of the risk register and other SSCs will replace them because of the iterative nature of the methodology. The equipment assessments and risk matrix are living documents so when SSC scores and risks evolve, the risk register will reflect that evolution.

Availability vs. Risk Register Comparison

Based on a comparison of the risk register and the LANSCE Availability Data, it is clear that many of the acute SSC failures of previous run cycles have already been addressed by equipment owners. Lower cost risks are currently being funded out of group budgets while higher cost, chronic or end-of-life SSCs tend to get resolved by separate funding. Budget allocations made in FY 2018 and 2019 are addressing all of the SSCs in the first risk register. Near end-of-life equipment includes some wire scanners, magnet power supplies and boost pump water systems.

In the previous paper [1], the explanation of the equipment assessment process involves weighting of criteria used to evaluate and compare SSCs to each other. The weighting process itself can propel or diminish SSC scoring. A potential improvement in the process could be to gear the weightings more toward metrics such as reliability, availability, maintainability and utilization. In fact, a case in point is described below.

Not evident in the data is the time after maintenance outages and source recycles to retune the beam to the EAs. Machine turn on remains one of the single biggest challenges at LANSCE in terms of time consumption. Many accelerators today use non-intercepting beam position and phase monitors (BPPMs) as inputs and steering magnet currents as outputs to form a transfer-function in which to establish and maintain a desired beam trajectory. LANSCE uses a combination of wire scanners, phosphorescent screens and BPMs to steer. Recent financial allocations have been made toward a transfer function methodology that replaces inoperable wire scanners with new ones and installs BPPMs at strategic locations along the accelerator. Optimally locating the BPPMs is a challenge since many areas of the beamline do not have available real estate in which to install these devices. Not an insurmountable problem, careful planning and ingenuity negates this issue.

Improved diagnostic coverage and automated beam steering should increase the utilization at the EAs, perhaps by a large margin. Although not necessarily increasing the availability, reducing the time required to recover beam transport will translate into more experimental time offered to the LANSCE user communities.

Conclusion

A risk-based approach to improving beam availability at LANSCE has been implemented and continues to be developed. The goal is to use this approach, in conjunction with metrics data, to optimize the use of limited operational resources while improving beam performance and availability. Several more years are likely required to fully develop this analytical approach for strategic maintenance and to realize all of its benefits.

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